Multi-Task Inverse Dynamcis based on LS-Optimization

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This paper presents the latest advances we made in static and dynamic locomotion with our compliant quadrupedal robot StarlETH. We outline a hierarchical task-space inverse dynamics framework based on least square optimization that allows for simple generation of complex robot behaviors and simultaneous optimization of joint torque and contact force objectives. Strong focus is put on experimental validation[1].

1 Motivation

Legged robotic devices, and in particular quadrupedal systems, have made significant progress in the past years. Such artificial systems have broken records in fast running (Boston Dynamic's Cheetah, [2]), in efficient walking (Cornell Ranger, [1]) or in climbing difficult obstacles (LittleDog challenge, e.g. [5]). Towards combining these features in a single robotic device, we developed the mid-dog sized quadruped Starl*ETH* [3](Figure 1). This machine is driven by highly compliant SEAs that ensure robustness in dynamic maneuvers, that enable intermittent energy storage, and most importantly for the present paper, which allow to precisely control joint torques.

Controlling such a robot is a challenging problem due to the high-dimensional, nonlinear, non-smooth and underactuated system dynamics. It requires to generate the motion as a function of different objectives that have to be simultaneously executed (e.g. ensuring stability, moving a foot point, or keeping certain posture). At the same time, the contact forces and joint torques must be distributed to satisfy stability constraints at the interaction points and to optimize energetic efficiency.

2 State of the Art

Towards controlling the behavior of complex legged systems, promising results were published along the lines of Khatib's seminal work on Operational Space Control (OSC) [6]. His group extended this method to a prioritized description for floating based systems [11, 8] which guarantees that important tasks are executed by all means, while less important ones are fulfilled as good as possible. However, experimental results on walking machines are still missing.

Another group made progress in applying inverse dynamics techniques based on kinematic projections in hardware experiments [7]. They later presented a special inversion method for kinematically projected, support consistent equations of motion that allows to optimize a quadratic cost function in joint torques and contact forces [10]. An advantage of this method is that it requires to invert only accurately available and well conditioned kinematic system properties [9].

[1]illustration available at http://www.youtu.be/7F6GRFPkdp0

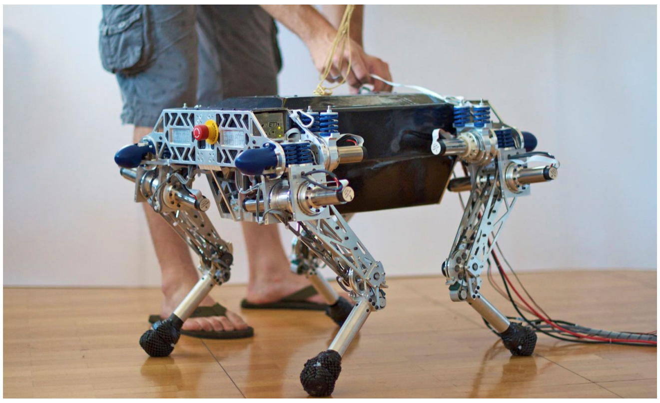

Figure 1: Starl*ETH*: A compliant quadruped robot.

3 Own Approach

To combine advantages of the task decomposition and the kinematic projections, we present a hierarchical task-space inverse dynamics controller. In this framework, the multi-objective task-space dynamics, the inversion of the equations of motion, as well as the optimization of joint torques and contact forces are described as least square problems with an associated priority level. Actuator torque commands are generated from this hierarchical description of the robot behavior using an analytical solution for prioritized least square optimization [4].

4 Results

The present approach is extensively tested in static walking and dynamic trotting experiments using our quadrupedal robot Starl*ETH*. In static walking with 3 or more legs in contact, the robot encounters a large support null-space that allows to change the load distribution without influencing the motion of the robot. We present ways to optimize the actuator efficiency and to minimize the risk of slippage. This enables walking in rough terrain by exploiting internal force directions while clinging to the ground. It is further possible to achieve smooth changes in contact forces by interpolating between subsequent contact situations, and to account for joint torque and position limitations by keeping a variable hierarchy in the tasks. In dynamic locomotion experiments, we further demonstrate that the presented control algorithm allows for robust trotting under significant external disturbances with a truly-underactuated system that can even undergo full flight phases.

5 Best Possible Outcome

The present method will be extended to enhance the locomotion skills of Starl*ETH* towards other gaits and more challenging terrain. The simultaneous motion and contact force optimization offers potential for running and climbing maneuvers that is not achieved so far.

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